

A Calculus of Consistent Component-based Software Updates

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Abstract

It is important to enable reasoning about the meaning and possible effects of updates to ensure that the updated system operates correctly. A formal, mathematical model of dynamic update should be developed, in order to understand by both users and implementors of update technology what design choices can be considered. In this paper, we define a formal calculus *update π* , a variant extension of higher-order π calculus, to model dynamic updates of component-based software, which is language and technology independent. The calculus focuses on following main concepts: proper granularity of update, timing of dynamic update, state transformation between versions, update failure check and recovery. We describe a series of rule on safe component updates to model some general processes of dynamic update and discuss its reduction semantics coincides with a labelled transition system semantics that illustrate the expressive power of these calculi.

Keywords: process calculus; formal method; dynamic update; component-based software; higher-order language.

1 Introduction

Dynamic update[7, 10] is a general, software-based technique: there is no need for redundant hardware or special-purpose software architecture, and application state can be naturally preserved between updated versions, so that current processing is not compromised or interrupted. Most current works about software update(e.g. [1, 7, 8, 10, 14]) concentrate on techniques and implementations of bug-fixes or performance enhancements. They implement some well-established update methods for global synchronization of local updates or distributed updates. But they lack both simplicity and generality and it is not clear what properties are actually guaranteed. Therefore, we believe a formal, mathematical model of dynamic update should be developed, in order to understand what design choices can be considered, and what impact they have on update complexity and scalability. There a few formalization works have been carried out to support the correctness and consistency derivations of dynamic update (e.g. [3, 15, 13]. Nevertheless, we are not aware of past efforts that have well formalized the models for timing of update, state transformation, and update failure recovery.

To be able to reason and ensure properties about system specifications supporting dynamic component updates, we need mathematical tools. Process calculi are one suitable tool, providing not only a description language, but a rigorous semantics as well, allowing the proof of relevant properties. In this paper, we define a formal calculus *update π* to model dynamic updates of component-based software, which is language and technology independent. This calculus is an extension of the asynchronous, polyadic and higher-order π -calculus based on the fact that dynamic updates can be seen as interactive behaviors, message-passing asynchronously, within a component-based system. Some important aspects on dynamic component update, which ranging from proper granularity of update, timing of dynamic update, state preservation and transformation, and update failure check and recovery, will be modeled and reduced in our calculus.

The rest of this paper is organized as follows. In Section 2, we review the main considerations behind different constructs of the *update π* calculus, and then present the syntactical and structural descriptions of

update π calculus. We describe in Section 3 a series of rule on safe component updates to model some general processes of dynamic update and some well-defined update mechanism. The reduction semantics of the *update* π calculus are defined in Section 4, and show that the reduction semantics coincides with a labelled transition system semantics, under sufficient conditions on the interaction of processes with the environment, that illustrate the expressive power of this calculi. In section 5, we discuss related works on mechanisms and formalism of dynamic updates. Section 6 concludes the paper with a discussion of further work.

2 The *update* π Calculus

In this section, we firstly motivate some design choices by introducing informally the main elements about a dynamic component update and the main constructs of the *update* π calculus. Then we present the syntactical and structural descriptions of *update* π calculus, as a calculus for modeling dynamic updates of component-based software, with a location concept to model the hierarchical composition of components, a process sequence to model the timing of updates, an accompanied process to model executed log of updates, and a state increment or decrement mechanism to model state preservation and transformation.

2.1 Design Choices

The *update* π calculus inherits ideas from numerous previous studies, included safe and timely dynamic updates[10, 13], and higher-order calculus(specially, Kell calculus [12]). It is built as an extension of the higher-order π -calculus, and observes several main design principles which we consider important for a foundational model of dynamic component update: trusted update sources, reasonable timing of update, and consistent state transformation.

In *update* π calculus, exactly as in Kell calculus, we use the hierarchical and programmable locality concept as a primitive form of component that can be used simultaneously as a unit of modularity, of isolation, and of passivation(the ability to freeze and marshal a component during its execution). The *update* π calculus is in fact a family of higher-order process calculi with a special update locality, which shares the same basic operational semantics rules with the other calculus, but differ in the language used to define specified update mechanisms in input and output constructs, and affiliate a state description for each process. Furthermore, contrarily to some existing proposals, we interpret the names declared inside a locality as private resources, that should remain local to that locality. Neither do we include an axiom of form $l[(\nu n)P] \equiv (\nu n)l[P]$ in structural congruence, nor do we implement name extrusion across locality boundaries along reduction steps that would require it(similar to some existing implementations of π -calculus-related process algebras[5]). This design choices avoid ambiguous diversity of reduction pathes in located process $l[P]$, and enable safety of programmable locality where the resources are not extravasate outside their owner.

The timing of an update, as many past researchers have observed, is critical to ensuring the validity[6, 7]. This synchronous update primitive dictates when an update can occur, and makes it easier to understand the states of program which an update is applied to than the alternative asynchronous approach, in which an update could occur at any time. Some researches[7, 8] have proved that synchronous updating makes it easier to write correct updates. So some safe update points specified by a programmer or implementor of updated software can express explicitly the update requirements and favor to derive safe and timely software updates. In our calculus, the process sequence $P ; Q$ forces a temporal order between the two operands: process Q will be activated only after successful completion of P . Through the process sequence, safe update points can be set in feasible locations of whole programs, thus the timing of update is enforced by some temporal operands of the sequential composition operator.

Without care, after several updates the state of an updated system can become confusing, particularly when updates are in terms of binary patches. Replacements and transformations must not interfere with application access to the objects, and must be performed efficiently in both space and time. However, the state to be transformed might be corrupted (e.g., update for bug fixes) and detecting and transforming a corrupted state to a non-corrupted state is the quintessential state transformation problem. For simplicity and without loss of generality, in this paper, we assume that the state is not corrupted and the transformation can be done safely

so that important consistency is not broken. We propose an approach to associate a state information to each process, where all instant output actions of a process are recorded. In our calculus, a related state δ is defined for each process. The process state is composed of some output actions generated after execution of the process, which denote the results of execution and are expressed through the names as channels or locations.

2.2 The Syntax

The syntax of *update* π calculus is given in Figure 1. Similar to standard π -calculus processes, we use 0 to denote a null process that does not perform any action, X to denote a unknown process which is waiting for an assignment, $P \mid Q$ to denote the parallel composition of two processes to allow processes to interact, and $(\nu n)P$ to denote the name restriction, in which the creation of a fresh name n whose initial scope is the process P . The process sequence $P ; Q$ forces a temporal order between the two operands: process Q will be active only after successful completion of P . In this process sequence, a sequence operator $;$ split two processes, where process P is assigned as a predecessor of the operator $;$ and then process Q is a successor of this operator.

The interfaces of component are modeled by channels, thus the output and input behaviors can be expressed through some actions on channels. The channels can carry extensible records, which model message exchanges between components through input and output interfaces. An output on channel a is noted $\bar{a}\langle\omega\rangle$, where ω is a constant argument that can be a name n or a process P . Specially, no continuation is to afflicted each output action because we consider the output process is parallel to other processes. Similar to Kell calculus, we use the located process concepts, by the term $l[P]$, to model software components for hierarchical composition. In the term $l[P]$, l is the name of the locality, that is, a identifier of location in which the components are stored before the composition, and P is the process identifier of a single process, a process composition or a process sequence executing at location l .

It is worth of notice that in an input trigger $\xi * P$, the operator between input pattern ξ and continuation process P is $*$ rather than \cdot , used in standard π -calculus. There exist two cases for this operator: \triangleright and \diamond , where the former is a disposable trigger operated only once and however the latter can be preserved during a reduction. Our calculus implement the primitive for recursion or replication through the \diamond operator, which can model asynchronous message passing between concurrent components. For example, the process $\bar{a}\langle Q \rangle \mid a(X) \diamond P$ will be induced to $a(X) \diamond P \mid P\{Q/X\}$, where $\{Q/X\}$ denotes a capture avoiding substitution of process variable X with process Q . $a(x) * P$, $a(X) * P$ respectively stands for a process willing to acquire a resource: this can mean either receiving a first-order or higher-order message. The input prefix ξ and restriction operator ν act respectively as a binder in the calculus. We write $\text{fn}(P)$ and $\text{fv}(P)$ respectively for the free names and free variables of process P . Furthermore, we use the standard notions of free names of processes and of α -equivalence. We note $P =_\alpha Q$ when two terms P and Q are α -convertible.

The channel of transmitting the update packages is specified by the name up , thus its output process is expressed through the term $\overline{\text{up}}\langle l, P \rangle$ in our calculus. For the receiver of update messages, in which the updates are executed concretely, we define the pattern parameterized process term $\text{up}(l, X) \# R \diamond P$ to receive the matched update package on channel up , and then to activate and execute the actual updates. Noteworthily, it is possible that an update falls failure ascribe to some inadequate checks of compatibility before update and some accidents during update. Thus we introduce a concept of update log, which allows to incrementally build the log of updates when each update execution. In the term $\text{up}(l, X) \# R \diamond P$, the sub-expression $\# R$, in which R is an accompanied process, is used to associate to each update a process that records the trace to be stored upon update message reception. When the update of a process P incurs a recoverable failure, we block the execution of P . This is modeled through the blocked process $\llbracket P \rrbracket$ that behaves as P but cannot be activated until it is restored when the execution of a well-defined update failure recovery (or rollbacking).

A state δ is a multiset of names that represents the output actions or resources visible to the update when it was initiated. In the following, we write $\delta \uplus \{a\}$ for the multiset δ enriched with the name a and $\delta \setminus \delta'$ for the multiset obtained from δ by removing elements found in δ' , that is the smallest multiset δ'' such that $\delta \subseteq \delta' \uplus \delta''$. The symbol \emptyset stands for the empty multiset while $\{a^n\}$ is the multiset composed of exactly n copies of a , where $\{a^0\} = \emptyset$. The evaluation of state is $\delta = \{a\}$, which a is an output action, if $\bar{a}\langle n \rangle$ or $\bar{a}\langle P \rangle$ is a valid process of the current updated components, and $\delta = \{l\}$, which l is an output resource, if $l[P]$ is a valid process in the current

P, Q, R	$::=$		processes
		0	null process
		X	process variable
		$(\nu n)P$	name restriction
		$P \mid Q$	parallel composition
		$P ; Q$	process sequence
		$l[P]$	located process
		$\bar{a}\langle n \rangle.Q$	name output
		$\bar{a}\langle P \rangle.Q$	message output
		$\xi * P$	input process
		$\overline{\text{up}}\langle l, P \rangle$	update provision
		$\text{up}(l, X)\#Q \diamond P$	update reception
		$\llbracket P \rrbracket$	blocked process
ξ	$::=$	$a(\tilde{x}) \mid a(\tilde{X}) \mid l[\tilde{X}]$	input pattern
$*$	$::=$	$\triangleright \mid \diamond$	
δ	$::=$	\emptyset	null state
		$\{a\}$	output action, if $\bar{a}\langle n \rangle$ or $\bar{a}\langle P \rangle$ is a valid process
		$\{l\}$	output source, if $l[P]$ is a valid process
		$\delta \uplus \delta$	multiset of states
\mathbb{C}	$::=$	$\cdot \mid (\nu n)\mathbb{C} \mid \xi * \mathbb{C}$	process context
		$\mathbb{C} \mid P \mid \mathbb{C} ; P$	
		$l[\mathbb{C}] \mid \bar{a}\langle \mathbb{C} \rangle \mid \llbracket \mathbb{C} \rrbracket$	
		$\overline{\text{up}}\langle l, \mathbb{C} \rangle \mid \text{up}(l, X)\#Q \diamond \mathbb{C}$	
\mathbb{E}	$::=$	$\cdot \mid (\nu n)\mathbb{E} \mid P \mid \mathbb{E} \mid l[\mathbb{C}]$	execution context

Figure 1: Processes and states of *update π* calculus.

updated components.

3 Dynamic Component Update in *update π*

We describe in this section a series of rule on safe component updates to model general process of dynamic updates and possible update failures. And the time selection of dynamic update and the state preservation and transformation between versions also are enforced in our calculus. We first define formally two affiliated functions about state matchability and process compatibility as follows.

Definition 1. Two process state δ, δ' are said to be matchable (noted by $\text{match}(\delta, \delta')$), if $\delta \subseteq \delta'$ which means that δ, δ' are same or all output actions visible to the update in set δ are also included in the set δ' .

Definition 2. Two processes P, Q are said to be compatible (noted by $\text{comp}(P, Q)$), if all output and input interfaces of the constituent components in process P are compatible with those in process Q .

3.1 Safe Update of Component

We assumed that the component is abstracted with a located process which can be a composition of multi-components, thus in the output term $\overline{\text{up}}\langle l, P \rangle$, l is a locality identifier of the enclosing updatable components, which is defined by the programmer of update packages. That is, the identifier and its version information of

$$\begin{array}{c}
\frac{l = k \quad \text{match}(\delta, \delta') \quad l[P] \mid (k[X] \triangleright k[Q]) : \{l\} \uplus \delta \rightarrow k[Q\{P/X\}] : \delta'}{\overline{\text{up}}\langle l, P \rangle \mid \text{up}(k, X) \# R \diamond k[Q] : \{l\} \uplus \delta \rightarrow \text{up}(k, X) \# R \diamond k[Q] \mid \llbracket R\{P/X\} \rrbracket \mid k[Q\{P/X\}] : \{l\} \uplus \delta'} \quad (\text{R.UPDATE.OK}) \\
\\
\frac{l \neq k \quad k[Q] : \delta \rightarrow k[Q'] : \delta'}{\overline{\text{up}}\langle l, P \rangle \mid \text{up}(k, X) \# R \diamond k[Q] : \{l\} \uplus \delta \rightarrow \overline{\text{up}}\langle l, P \rangle \mid \text{up}(k, X) \# R \diamond k[Q'] : \{l\} \uplus \delta'} \quad (\text{R.UPDATE.UNMAT}) \\
\\
\frac{l = k \quad !\text{comp}(P, Q)}{\overline{\text{up}}\langle l, P \rangle \mid \text{up}(k, X) \# R \diamond k[Q] : \{l\} \uplus \delta \rightarrow \text{up}(k, X) \# R \diamond k[Q] : \delta} \quad (\text{R.UPDATE.REST}) \\
\\
\frac{l = k \quad !\text{match}(\delta, \delta')}{\overline{\text{up}}\langle l, P \rangle \mid \text{up}(k, X) \# R \diamond k[Q] : \{l\} \uplus \delta \rightarrow \text{up}(k, X) \# R \diamond R\{P/X\} \mid \llbracket k[Q\{P/X\}] \rrbracket : \delta'} \quad (\text{R.UPDATE.FAIL})
\end{array}$$

Figure 2: Reduction semantics of safe component updates.

a to-update component specified through the name l in the update package. However, P is a process constant which specifies the concrete contents of the update package. Accordingly, in the input process term $\text{up}(l, X) \# R \diamond P$, l is location constant which can includes some version information, etc., used to specify a safe location of update. And the operator \diamond means that the safe location is replicative and can be preserved during a update.

During a component update, the two locality identifiers of output and input interface for updates will be compared to ascertain whether there is a pending update for the current component, through the check of name matchability and version correctness. Specially, if the version number of provided update package is larger than the one of current component, which founded on the assumptions of update in last section (in which we don't consider the backwards updates but only forwards updates), a safe update is triggered as illustrated in the rule (R.UPDATE.OK). Then the process P transmits the actual update operations to the target components $k[Q]$, and this is expressed by a capture avoiding substitution $\{P/X\}$ in rule (R.UPDATE.OK). And the states of new and old processes keep consistent during the update, which are expressed with state matchability $\text{match}(\delta, \delta')$. The sub-expression $\#R$ is used to associate to each update a process $R\{P/X\}$ that stores the associated runtime states upon update message reception. If the update is successful, the blocked process $R\{P/X\}$ will not be activated to promote the normal execution of program.

On the contrary, in rule (R.UPDATE.UNMAT), because the provided update package is incompatible with the current component, by which either smaller version number or unmatched component identifiers, the process P is not activated and the target components will perform its intrinsical functions as normal. However, even if the version numbers and component identifiers are validated, the update will be restrained when the injected process P and the to-update process Q are incompatible as illustrated in rule (R.UPDATE.REST).

We assume that each update is well-defined, can be recovered from failures. The process R is an accompanied log process to store the executed actions of an update, which to be backtracked in case the update fails. To account for possible failures of the update process, the accompanied process R , which records the trace information of executed update and becomes critical part of the recovery process of the update., will be activated for backtracking and recovery to abort invalid updates. The process R has no activity until a failure occurs, becoming then the recovery process R . When an update action occurs. the associated log process is stored and becomes part of the recovery process of the update. In rule (R.UPDATE.FAIL), the version numbers and component identifiers are validated and the injected process P and to-update process Q are compatible, but the two states of new and old processes are inconsistent during the update. It means that the update of process Q incurs a recoverable failure, we block the execution of $Q\{P/X\}$. This is modeled through the blocked process $\llbracket Q\{P/X\} \rrbracket$ that behaves as $Q\{P/X\}$ but cannot be activated until it is restored from a well-defined update failure recovery (triggered by the recovery process $R\{P/X\}$).

3.2 Timing of Update

In our calculus, the process sequence $P ; Q$ forces a temporal order between the two operands: process Q will be activated only after successful completion of P . Through the process sequence, safe update points can be set in some feasible locations of whole programs, thus the timing of update is enforced by this temporal operands of the sequential composition operator. For example, if a update can occur after the execution of process P and before the execution of process Q , then as process sequence $P ; \text{up}(k, X) \# R \diamond k[Q]$, a safe update point will be assigned to the process Q . During the execution of process P , a update corresponding to this update point will be pended until the process Q is about to be activated. On the contrary, if the process Q is not the process which is about to be activated immediately in next time, then this update will keep pending. By dictating when an update can occur, makes it easier to understand the states of the program which an update is applied to. And through this mechanism, we allows the lazy updates[4] which the component is not updated until the to-update process is about to execute.

3.3 State Transformation

State transformation is meaningful to map a state of the old application to a state of the new one. In our calculus, a state δ is a multiset of names that represents the output actions visible to the update when it was initiated. At the time of an update, a well-defined state transformation function is executed from component entry points. Then the state δ recorded in the updated process (the state at the initiation of the update) will be compared with the current state δ' (the mapped state when the update ends) to check if the update have concurrently made changes to the updated components for consistency. If the new state δ' is consistent with the old one δ (that is, they satisfy the Definition 1, denoted as $\text{match}(\delta, \delta')$), the updated component will be able to preserves the old execution. In other words, the component update is successful as illustrated the rule (R.UPDATE.OK). Otherwise, if the two states δ and δ' are verified to be inconsistent (denoted as $\text{!match}(\delta, \delta')$), as in the rule (R.UPDATE.FAIL), the update will fall into be fail to activate the update recovery process $R\{P/X\}$.

4 Operational Semantics

The operational semantics of a process algebra is traditionally given in terms of a labelled transition system describing the possible evolution of a process. In general, it is not easy to define directly a labelled transition system. The manipulation of names and the side conditions in the rules are non-trivial. On the other side, if the reduction system is available, the corresponding labelled transition system can be found. Furthermore, by showing the correspondence of both the reduction system and the labelled transition system it is possible to prove the correctness of the latter.

4.1 Structure Congruence

The structural congruence relation, written by \equiv , equates all processes we will never want to distinguish for any semantic reason.

Definition 3. *Structure congruence \equiv is the smallest equivalence relation on execution process that satisfies the α -conversion law, and the axioms given in Figure 3.*

Noted that we do not allow 0 as a successive neutral element, as in rule $P ; 0 \equiv P$, because after the execution of process P , its successor split with a sequence operator $;$ is not always executed. Because the blocked process $\llbracket P \rrbracket$ behaves as P but cannot be activated until a well-defined update failure recovery is executed, the ν restriction operation, as in rule (S.NU.BLK), can extrude to the top level of a block. And it behaves as P when a blocked process $\llbracket P \rrbracket$ is activated, so we use the rule (S.EXEC.BLK) to indicate that the execution of process $\llbracket P \rrbracket$ and P are not distinguishable. And it should be clarified that besides the process output itself, the output $\bar{a}\langle P \rangle$ also delegate name output $\bar{a}\langle n \rangle$, located process output $l[P]$ and update provision $\overline{\text{up}}\langle l, P \rangle$ in this rule.

$$\begin{array}{c}
P \mid Q \equiv Q \mid P \quad (\text{S.PAR.C}) \qquad P \mid (Q \mid R) \equiv (P \mid Q) \mid R \quad (\text{S.PAR.A}) \\
\\
P \mid 0 \equiv P \quad (\text{S.PAR.N}) \qquad P ; (Q ; R) \equiv (P ; Q) ; R \quad (\text{S.SEQ.A}) \\
\\
0 ; P \equiv P \quad (\text{S.SEQ.N}) \qquad (\nu x)0 \equiv 0 \quad (\text{S.NU.NIL}) \qquad \llbracket 0 \rrbracket \equiv 0 \quad (\text{S.BLK.NIL}) \\
\\
(\nu x)(\nu y)P \equiv (\nu y)(\nu x)P \quad (\text{S.NU.C}) \qquad \llbracket (\nu x)P \rrbracket \equiv (\nu x)\llbracket P \rrbracket \quad (\text{S.NU.BLK}) \\
\\
\frac{x \notin \text{fn}(P)}{P \mid (\nu x)Q \equiv (\nu x)(P \mid Q)} \quad (\text{S.NU.PARR}) \qquad \frac{x \notin \text{fn}(Q)}{(\nu x)P \mid Q \equiv (\nu x)(P \mid Q)} \quad (\text{S.NU.PARL}) \\
\\
\frac{x \notin \text{fn}(P)}{P ; (\nu x)Q \equiv (\nu x)(P ; Q)} \quad (\text{S.NU.SEQS}) \qquad \frac{x \notin \text{fn}(Q)}{(\nu x)P ; Q \equiv (\nu x)(P ; Q)} \quad (\text{S.NU.SEQP}) \\
\\
\frac{a \notin \text{bn}(Q)}{(\bar{a}\langle P \rangle \mid R) ; Q \equiv \bar{a}\langle P \rangle \mid R ; Q} \quad (\text{S.SEQ.OUT}) \qquad \frac{a \notin \text{bn}(Q)}{(\bar{a}\langle P \rangle \mid R) \mid Q \equiv \bar{a}\langle P \rangle \mid R \mid Q} \quad (\text{S.PAR.OUT}) \\
\\
\frac{\xi \equiv \zeta}{\xi * P \equiv \zeta * P} \quad (\text{S.PTN.IN}) \qquad \frac{l \equiv l' \quad Q \equiv Q' \quad P \equiv P' \quad X \in \text{fv}(P) \cap \text{fv}(P')}{\text{up}(l, X)\#Q \diamond P \equiv \text{up}(l', X)\#Q' \diamond P'} \quad (\text{S.UPDATE.REV}) \\
\\
\frac{P =_{\alpha} Q}{P \equiv Q} \quad (\text{S.ALPHA}) \qquad \frac{P \equiv Q}{\mathbb{C}\{P\} \equiv \mathbb{C}\{Q\}} \quad (\text{S.CONTEXT}) \qquad \mathbb{E}\{\llbracket P \rrbracket\} \equiv \mathbb{E}\{P\} \quad (\text{S.EXEC.BLK})
\end{array}$$

Figure 3: structure congruence relations of processes.

Notice also that the Ambient-like rule $l[(\nu x)P] * Q \equiv (\nu x)l[P] * Q$ and $l[(\nu x)P] \equiv (\nu x)l[P]$ are not allowed when $x \notin \{l\} \cup \text{fn}(Q)$ to enable the safety of programmable locality where the resources are not extruded outside their owner. Furthermore, in rule (S.PTN.IN), (S.UPDATE.REV), (S.ALPHA), and (S.CONTEXT), we rely respectively on the structural congruence relation on input patterns, update reception, α -conversion, and process context.

4.2 Reduction Semantics

Figure 4 gives the reduction semantics of processes in *updater* π calculus. A reduction is of the form $P : \delta \rightarrow P' : \delta'$ where δ is the state of process P and δ' is an evolution of δ . For simplicity, the state δ only records the names of all output actions visible to P when reduction happens. It grows when an output representing an internal processing result is produced along with the execution of processes, and shrinks when an output or resource is consumed, as illustrated in rule (R.OUT.NAME), (R.OUT.PROC), (R.OUT.PASS), (R.UPDATE.PRIV), (R.IN.NAME), (R.IN.PROC) and (R.IN.PASS) where the process constant P has state δ .

Specially, the shrinkage semantics of state are also reflected with rules (R.UPDATE.OK), (R.UPDATE.REST), (R.UPDATE.UNMAT) and (R.UPDATE.FAIL) in Figure 2. And these reduction rules govern the dynamic updates of components, which allow to recover a failed update since those stored state information are not discarded. This design choice was influenced by an expected feature of update handlers: the possibility to recover updates locally spoiled or completed failures, where by completed failure we mean a update giving rise to the recoverable failures of several constituent components in a application module. This feature would not have problems of feasibility in a real system, since it could be associated to our calculus a distributed garbage collection [17] to remove recoveries of update no longer essential.

In rule (R.COMM), it can be concerned that the process P provides some consumable resources, denoted by state δ , and then the process Q consumes these resources. However, in process $P ; Q$, besides the sequence in time, there is no interaction between them. So the evolution of process P and Q can be respectively fulfilled, as in rule (R.SEQ.FST) and (R.SEQ.BOTH), where the latter explicitly expresses temporal order between them. Rule (R.RES) and (R.BLK) deal respectively with the initiation of an located process and an blocked process: an ongoing located resource or process block is created which holds the newer evaluation state δ' . Furthermore, in equivalence rule (R.EQV) and α -conversion rule (R.ALPHA), the two reduction relations depend on a matchability relation, match, which associates pairs consisting of two states. As illustrated in Definition 1, this matchability relation is assumed that define how a single state matches the other single state

$$\begin{array}{c}
\bar{a}\langle n \rangle : \{a\} \rightarrow 0 : \emptyset \quad (\text{R.OUT.NAME}) \qquad \bar{a}\langle P \rangle : \{a\} \uplus \delta \rightarrow 0 : \emptyset \quad (\text{R.OUT.PROC}) \\
\\
l[P] : \{l\} \uplus \delta \rightarrow 0 : \emptyset \quad (\text{R.OUT.PASS}) \qquad \overline{\text{up}} \langle l, P \rangle : \{l\} \uplus \delta \rightarrow 0 : \emptyset \quad (\text{R.UPDATE.PRIV}) \\
\\
(\bar{a}\langle n \rangle \mid a(x) \triangleright P) : \delta \uplus \{a\} \rightarrow P\{n/x\} : \delta \quad (\text{R.IN.NAME}) \\
\\
\frac{\text{bn}(X) \cap \text{fn}(P) = \phi}{(\bar{a}\langle P \rangle \mid a(X) \triangleright Q) : \delta \uplus \{a\} \rightarrow Q\{P/X\} : \delta} \quad (\text{R.IN.PROC}) \\
\\
\frac{\text{bn}(X) \cap \text{fn}(P) = \phi}{(l[P] \mid l[X] \triangleright Q) : \delta \uplus \{l\} \rightarrow Q\{P/X\} : \delta} \quad (\text{R.IN.PASS}) \\
\\
\frac{P : \delta_1 \uplus \delta \rightarrow P' : \delta_1 \quad Q : \delta_2 \rightarrow Q' : \delta_2}{P \mid Q : \delta_1 \uplus \delta_2 \uplus \delta \rightarrow P' \mid Q' : \delta_1 \uplus \delta_2} \quad (\text{R.COMM}) \\
\\
\frac{P : \delta_1 \rightarrow P' : \delta'_1}{P \mid Q : \delta_1 \uplus \delta_2 \rightarrow P' \mid Q : \delta'_1 \uplus \delta_2} \quad (\text{R.PAR.L}) \quad \frac{Q : \delta_2 \rightarrow Q' : \delta'_2}{P \mid Q : \delta_1 \uplus \delta_2 \rightarrow P \mid Q' : \delta_1 \uplus \delta'_2} \quad (\text{R.PAR.R}) \\
\\
\frac{P : \delta_1 \rightarrow P' : \delta'_1}{P ; Q : \delta_1 \rightarrow P' ; Q : \delta'_1} \quad (\text{R.SEQ.FST}) \quad \frac{P : \delta_1 \rightarrow P' : \delta'_1 \quad Q : \delta_2 \rightarrow Q' : \delta'_2}{P ; Q : \delta_1 \uplus \delta_2 \rightarrow P' ; Q' : \delta'_1 \uplus \delta'_2} \quad (\text{R.SEQ.BOTH}) \\
\\
\frac{P : \delta \rightarrow P' : \delta'}{l[(\nu x)P] : \delta \uplus \{l\} \rightarrow l[(\nu x)P'] : \delta' \uplus \{l\}} \quad (\text{R.RES}) \quad \frac{P : \delta \rightarrow P' : \delta'}{[[P]] : \delta \rightarrow [[P']] : \delta'} \quad (\text{R.BLK}) \\
\\
\frac{P \equiv P' \quad \text{match}(\delta_1, \delta'_1) \quad P' : \delta'_1 \rightarrow Q' : \delta'_2 \quad Q' \equiv Q \quad \text{match}(\delta'_2, \delta_2)}{P : \delta_1 \rightarrow Q : \delta_2} \quad (\text{R.EQV}) \\
\\
\frac{P =_\alpha P' \quad \text{match}(\delta_1, \delta'_1) \quad P' : \delta'_1 \rightarrow Q : \delta_2}{P : \delta_1 \rightarrow Q : \delta_2} \quad (\text{R.ALPHA}) \quad \frac{P : \delta_1 \rightarrow Q : \delta_2}{\mathbb{E}\{P\} : \delta_1 \rightarrow \mathbb{E}\{Q\} : \delta_2} \quad (\text{R.EXEC})
\end{array}$$

Figure 4: Reduction semantics for processes and states.

$$\alpha ::= \epsilon \mid \tau \mid a \mid \bar{a} \mid \alpha \mid \alpha \mid \alpha \uplus \alpha$$

Figure 5: Syntax of actions.

of process. The rule (R.EXEC) allows reduction to happen inside arbitrary execution contexts.

4.3 Labelled Transition Semantics

The reduction relation defines the interactive behavior of processes relative to a context in which they are contained, however, it covers only a part the behavior of processes, i.e., their local evolution. In other words, the reduction semantics describes how a process may interact with another, but not how this process (or parts of it) may interact with the environment. A labelled transition system describes these possible intraactions of processes with the environment. It is easy derive labels from the reduction semantics given in Figure 4. We first define the substitution as a (partial) function $\theta : (\mathbf{N} \rightarrow \mathbf{N}) \uplus (\mathbf{V} \rightarrow P)$ from names to names and process variables to *update* π calculus process. We write $P\theta$ the image under the substitution θ of process P .

To make a transition means that a process P can evolve into a process Q , and in doing so perform the action α . Actions are given by the grammar in Figure 5, where input and output describe interactions between an agent and its environment, while a special τ denotes interaction or silent action. Roughly speaking, transitions labelled with τ correspond to the plain reduction relation. Action ϵ , which $\bar{a} \mid a = \epsilon$, is introduced to signal the complete match of messages with an input pattern in a trigger. By definition, the parallel operator \mid on actions is associative and commutative, and has ϵ as a neutral element. The multiset of actions is defined with the \uplus operator, i.e. $\alpha \uplus \alpha$, which enforces the sequential execution of two actions.

In LTS semantics in Figure 6, one first can note that in the labelled transition relation (in Figure 6), $\bar{a}\langle n \rangle$, $\bar{a}\langle P \rangle$, $l[P]$ and $\overline{\text{up}} \langle l, P \rangle$ all give rise to a out transition which respectively has \bar{a} , \bar{a} , l and $\overline{\text{up}}$ as channel name. Specially, no continuation is afflicted each output action because we consider the output process is parallel to other processes, so all of these out transition will evolve out processes to 0. Second, all types of input actions

$$\begin{array}{c}
\bar{a}\langle n \rangle \xrightarrow{\bar{a}\langle n \rangle} 0 \quad (\text{T.OUT.NAME}) \quad \bar{a}\langle P \rangle \xrightarrow{\bar{a}\langle P \rangle} 0 \quad (\text{T.OUT.PROC}) \quad l[P] \xrightarrow{l[P]} 0 \quad (\text{T.OUT.PASS}) \\
\\
\overline{\text{up}} \langle l, P \rangle \xrightarrow{\overline{\text{up}} \langle l, P \rangle} 0 \quad (\text{T.UPDATE.PRIV}) \quad a(x) \triangleright P \xrightarrow{a(x)} P\theta : \delta \quad (\text{T.IN.NAME}) \\
a(X) \triangleright Q \xrightarrow{a(X)} Q\theta \quad (\text{T.IN.PROC}) \quad l[X] \triangleright Q \xrightarrow{l[X]} Q\theta \quad (\text{T.IN.PASS}) \\
\\
\text{up}(k, X) \# R \diamond k[Q] \xrightarrow{\text{up}(k, X)} \text{up}(k, X) \# R \diamond k[Q] \mid \llbracket R\theta \rrbracket \mid k[Q\theta] \quad (\text{T.UPDATE.OK}) \\
\\
\frac{P \xrightarrow{\alpha} P' \quad a \notin fn(\alpha)}{(\nu a)P \xrightarrow{\alpha} (\nu a)P'} \quad (\text{T.NU}) \quad \frac{P \xrightarrow{\alpha} P'}{[[P]] \xrightarrow{\alpha} [[P']]} \quad (\text{T.BLK}) \quad \frac{P \xrightarrow{\tau} Q}{l[P] \xrightarrow{\tau} l[Q]} \quad (\text{T.PASS}) \\
\\
\frac{P \xrightarrow{\epsilon} Q}{P \xrightarrow{\tau} Q} \quad (\text{T.RED}) \quad \frac{P \xrightarrow{\alpha} P' \quad \alpha \neq \epsilon}{P \mid Q \xrightarrow{\alpha} P' \mid Q} \quad (\text{T.PAR.L}) \quad \frac{Q \xrightarrow{\alpha} Q' \quad \alpha \neq \epsilon}{P \mid Q \xrightarrow{\alpha} P \mid Q'} \quad (\text{T.PAR.R}) \\
\\
\frac{P \xrightarrow{\alpha} P'}{P ; Q \xrightarrow{\alpha} P' ; Q} \quad (\text{T.SEQ.FST}) \quad \frac{P \xrightarrow{\alpha} P' \quad Q \xrightarrow{\beta} Q'}{P ; Q \xrightarrow{\alpha \circ \beta} P' ; Q'} \quad (\text{T.SEQ.BOTH}) \\
\\
\frac{P \xrightarrow{\alpha} P' \quad Q \xrightarrow{\beta} Q' \quad \alpha \neq \epsilon}{P \mid Q \xrightarrow{\alpha \mid \beta} P' \mid Q'} \quad (\text{T.COMM}) \quad \frac{P \xrightarrow{\alpha} P' \quad x \notin fn(\alpha)}{l[(\nu x)P] \xrightarrow{\alpha} l[(\nu x)P']} \quad (\text{T.RES}) \\
\\
\frac{P \equiv P' \quad P' \xrightarrow{\alpha} Q' \quad Q' \equiv Q}{P \xrightarrow{\alpha} Q} \quad (\text{T.EQV}) \quad \frac{P =_{\alpha} P' \quad P' \xrightarrow{\alpha} Q}{P \xrightarrow{\alpha} Q} \quad (\text{T.ALPHA})
\end{array}$$

Figure 6: Labelled transition system semantics for processes.

(e.g., $a(x)$, $a(X)$ and $\text{up}(k, X)$) or located resources (e.g., $l[X]$) will lead the bound names of an objective process to be substituted by the names in x or processes in X . Specially, in rule (T.UPDATE.OK), the process Q in location k is triggered to execute some well-defined update operations, noted by the substitution process $Q\theta$, and the accompanied process R is evolved to a blocked process $R\theta$. Third, the rules (T.NU), (T.BLK), (T.PAR.L), (T.PAR.R), (T.SEQ.FST) and (T.RES) signal that the transition of a process is not affected by ν restriction, block restriction, parallel or sequence operation and passivation. But it is also noted that the evolution of successive process must be triggered after a successful execution of its antecedent process, as in rule (T.SEQ.BOTH), where an explicitly temporal order is expressed between them.

5 Related Work

In general, the systems being updated dynamically are typically safety-critical, so it is important to select suitable timing of update to enable correct evolution of updated system. To make sure that the update is not performed while executing a specific code region, update authors can specify safe update points [8] or mark blocks of code that must be entirely executed on a single version of the system [9], as described in our update system which provides formal semantics to reduce safe update points. While these approaches have been effective in some real-world scenarios, they potentially suffer from a structural problem. Update safety constraints are hard-coded in the original version of the system and cannot be modified at update time. Thus in this paper, we provide formal semantics to reduce safe update point.

In [3], Bierman et al. proposed a typed λ -calculus, named by Update, to reduce dynamic software update, which multiple versions of a software component can co-exist in system. This method is relatively intuitionistic but difficult to implement owing to the requirement of multi-version coexist at one time. Similar to the idea in our method, Stoye et al.[13] developed a formal Proteus calculus to model dynamic update C-like programs, which assumed a new version has special signature different from its old version and all of updates are provably safe and consistent. Different from our method, these existing approaches have largely neglected some other important aspect, such as state preservation and transformation, possible update failure and recovery, while

focusing more on the executing process of update.

The ground ideas on our calculus inherit from some extended higher-order process calculi, e.g. M-calculus[11] and Kell-calculus[12], and specially the component-based software paradigm is represented with passivation which is similar to Kell-calculus. In complex systems, different updates may require very different conditions to be applied. When considering several categories of updates, the notion of transactional version consistency[13] can be generalized throughout the entire lifetime of a software system. In [16], the authors presented a calculus for modeling long running transactions within the framework of the π -calculus, with support for dynamic compensation as a recovery mechanism. In our calculus, the failure recovery of an update apply a similar mechanism to this dynamic compensation.

6 Conclusion and Future Work

In this paper, we propose a dynamic update calculus, *update π* calculus, based on extended higher order process calculi to model dynamic update of component-based software. The *update π* calculus is an attempt to extend the higher-order π calculus with passivation, and to enhance it, through the introduction of a family of dynamic component update mechanisms. The calculus focuses on the following main concepts: the feasible granularity of update, timing selection of dynamic update, state transformation between versions, possible update failures and recoveries. We describe a series of rule on safe component updates to model some general processes of dynamic update and discuss its reduction semantics coincides with a labelled transition system semantics that illustrate the expressive power of these calculi.

In general, state mapping problem is undecidable[6], but this does not mean that there is no any possibility to solve this problem automatically or semi-automatically[2]. In future works, we will manage to propose approaches to make us closer to achieve more practical and reductive state preservation and transformation. Furthermore, in a component-based system, it is relatively probable to cooperatively update several constituent components and some relative problems on this have been researched. So we will attempt to implement the cooperative update mechanism in future version of *update π* calculus. And also we will study the notions of bisimilarity and equivalence for the *update π* calculus, and discuss and prove some corresponding conclusions.

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